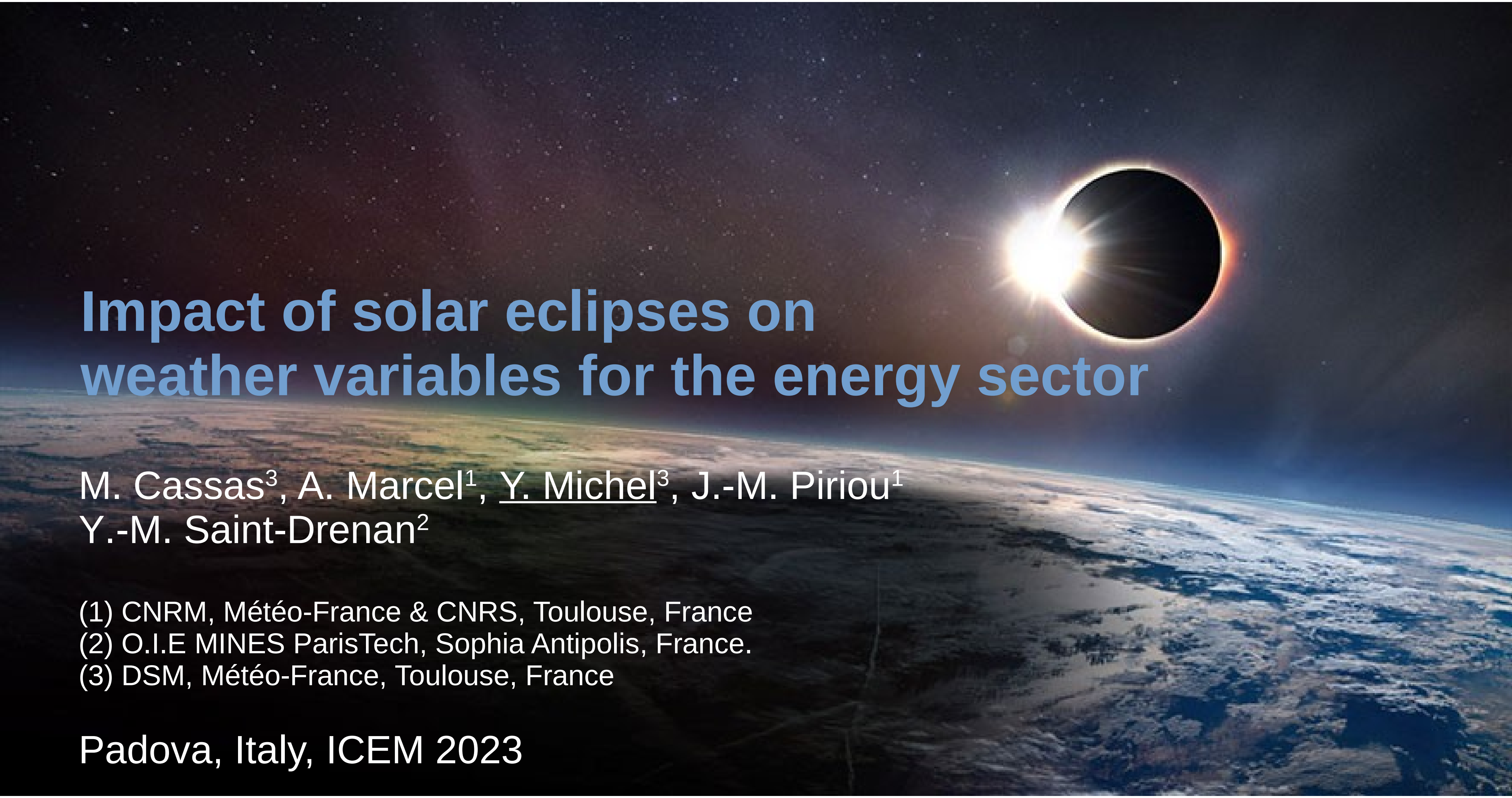

Impact of solar eclipses on weather variables for the energy sector

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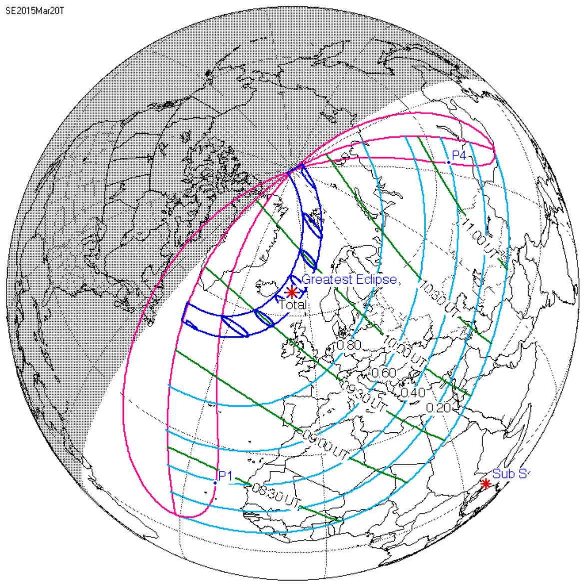
Padova, Italy, ICEM 2023

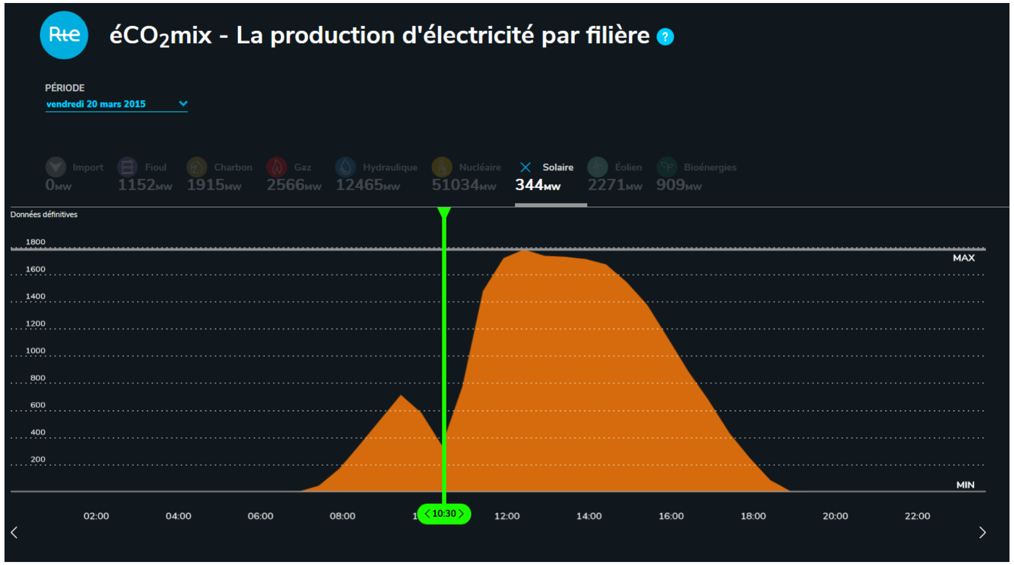
Solar eclipses : which impact for the energy sector ?

Impact on solar power generation

2015 : This was the first time that an eclipse had a significant impact on the power system, and the electricity sector took measures to mitigate the impact.



Map of the total solar eclipse of March 20, 2015 (latest total eclipse visible in Europe)



Solar power production over France on March 20, 2015 (RTE)

Solar eclipses : which impact for the energy sector ?

Impact on electricity demand

– possibly due to temperature decreases, up to 3K (Piriou et. Al, 1999; Gray and Harrisson 2012) ;

– and also to customers witnessing the eclipse (Munoz, Reuters, 2017)

… and also a minor impact on winds

(Clayton's 1901 « cold-cored eclipse cyclone hypothesis » ;

Gray and Harrisson 2012 : -0,7 m/s)

The Solar eclipse of March 20, 2015 in Sheffield, United Kingdom. All time local time (GMT)

Incorporating solar eclipses into a NWP model

Solar eclipses are predictable centuries in advance...

- first true prediction of a total solar eclipse (both in time and location) occurred in 1715 (Halley ; using Newton's theories of gravity and orbital mechanics)
- In this work we rely on the Canon of Solar Eclipses over 6000-yr using the lastest theories on Sun and Moon's coordinates developped at IMCCE
  - coordinates of the Sun based on the VSOP87 theory [Bretagnon and Francou, 1988]
  - Moon's coordinates based on the ELP-2000/82 theory [Chapront-Touze and Chapront, 1983].

The ARPEGE numerical model of Meteo-France

Model

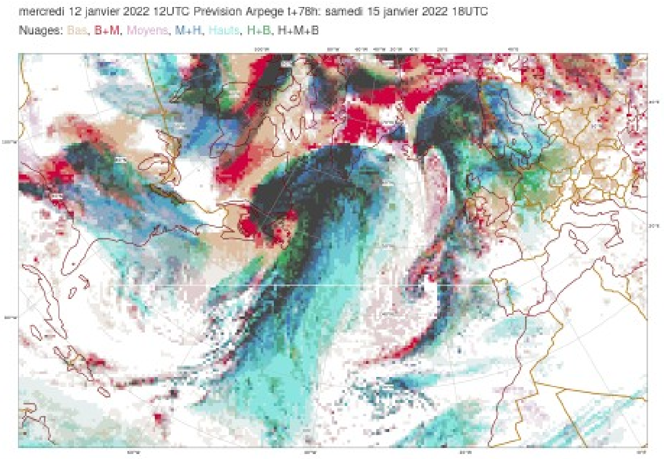
- primitive equations solved at a horizontal resolution around 5km over France on 105 vertical levels (10m-70km).
- The influence of physical processes (radiation, microphysics, surface processes) and the subgrid transport (turbulence, convection, gravity waves) are represented by parametrizations.

Initial Conditions

- based on a 4 dimensional variational assimilation (4D-Var) that incorporates a very large and varied amount of conventional observations and from remote sensing.

Forecasts

- Provides operational forecasts daily, up to day 5, 4x/day, deterministic and probabilistic (35 membres).



Cloud forecast with ARPEGE

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The AROME numerical model at Meteo-France

Model

- designed to improve short range forecasts of severe events such as intense Mediterranean precipitations, severe storms, fog, urban heat during heat waves...
- The physical parametrizations of the model come mostly from the research Méso-NH model whereas the dynamic core is the Non-Hydrostratic ALADIN one.

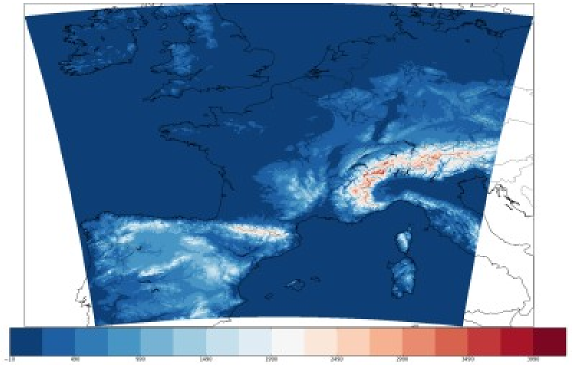
Initial conditions

- The model is initialized from 3D data assimilation. AROME is supplied, for instance, by hourly data from the ARAMIS radar network (doppler wind and precipitation).

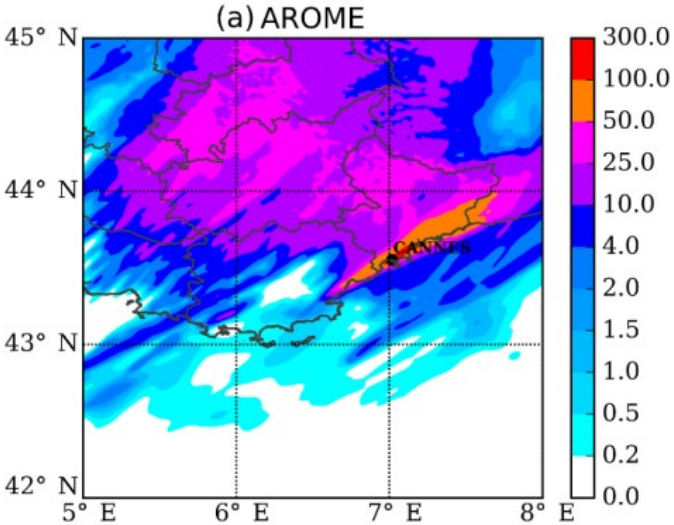
Forecasts

– Provides operational forecasts daily, up to day 2, deterministic and probabilitic (16 members).

– also available in French overseas.



Computationnal domain



Forecasting intense precipitation

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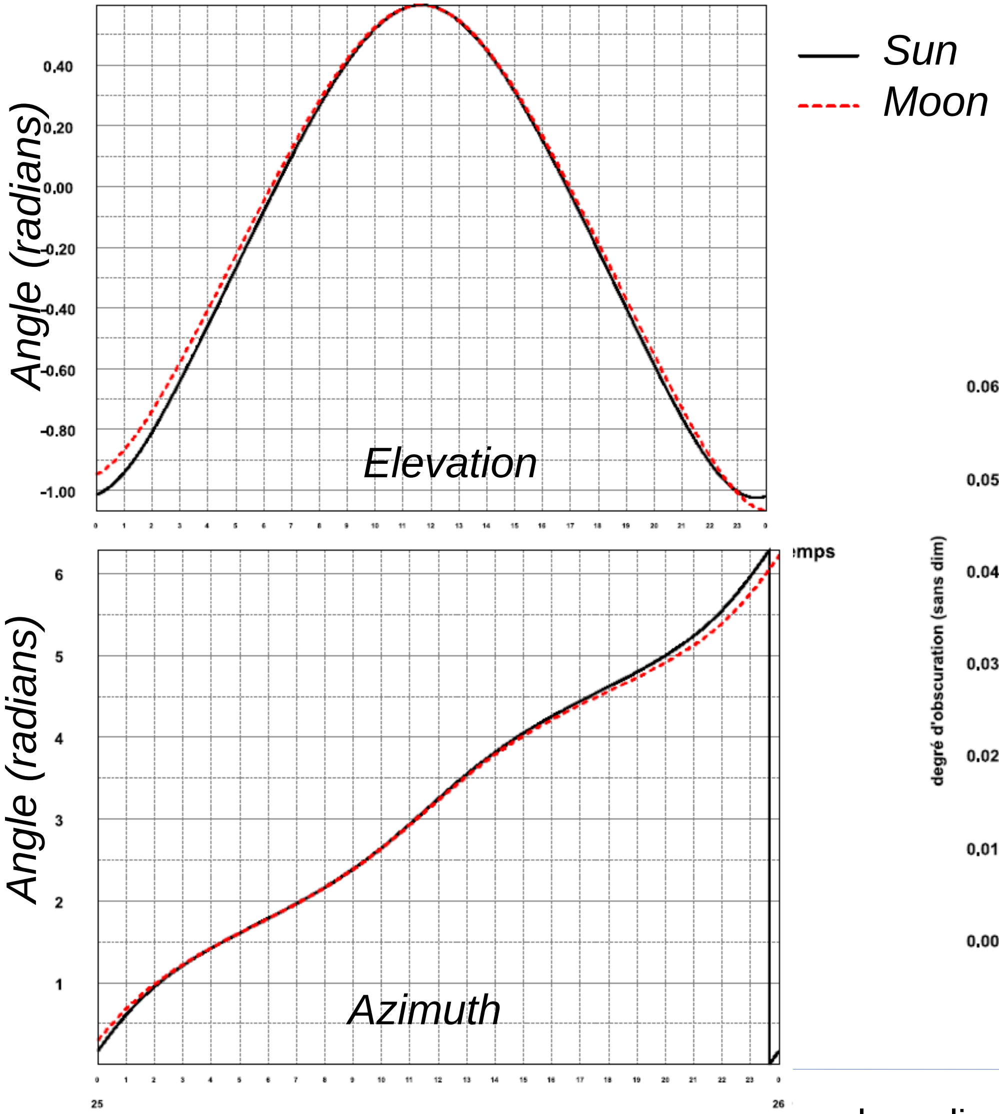
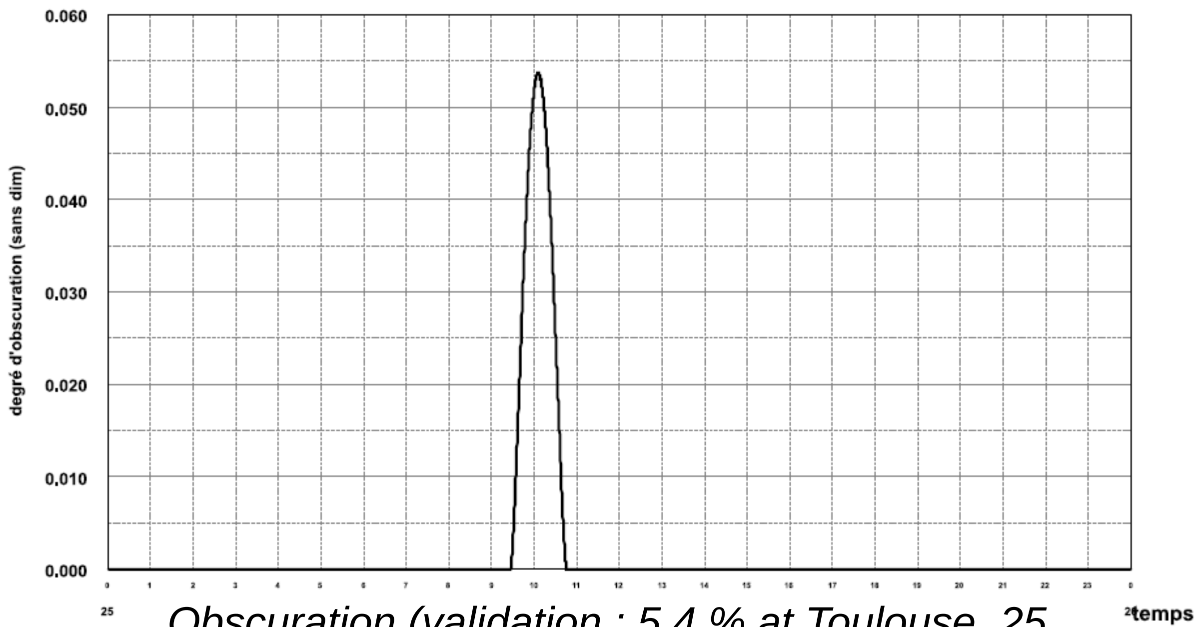
Incorporating solar eclipses into AROME and ARPEGE models



– Prediction of the Sun and Moon positions on Oct. 25, 2022, Toulouse, France (left).

– Computation of the eclipse obscuration : fraction of the Sun's surface area occulted by the Moon (bottom).



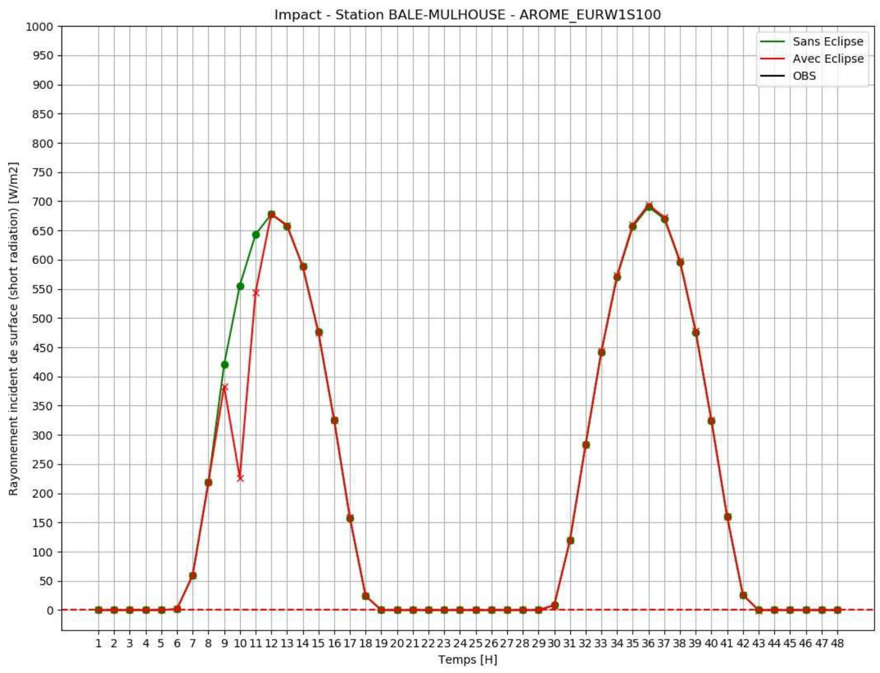
Obscuration (validation : 5,4 % at Toulouse, 25 Oct. 2022, 10 :04:48 UTC)

Incorporating solar eclipses into AROME and ARPEGE models

– solar radition downwards, at the top of the atmosphere, is affected by the obscuration.

– this implementation allows for full interaction with the models physics and therefore all meteorological variables.

– impact of the eclipse is deduced from the differences between simulations performed with and without the eclipse.



Forecasted surface short-wave (solar) radiation downwards at Bale-Muhouse, 25-26 Oct. 2022, with (red) and without (green) simulation of the solar eclipse.

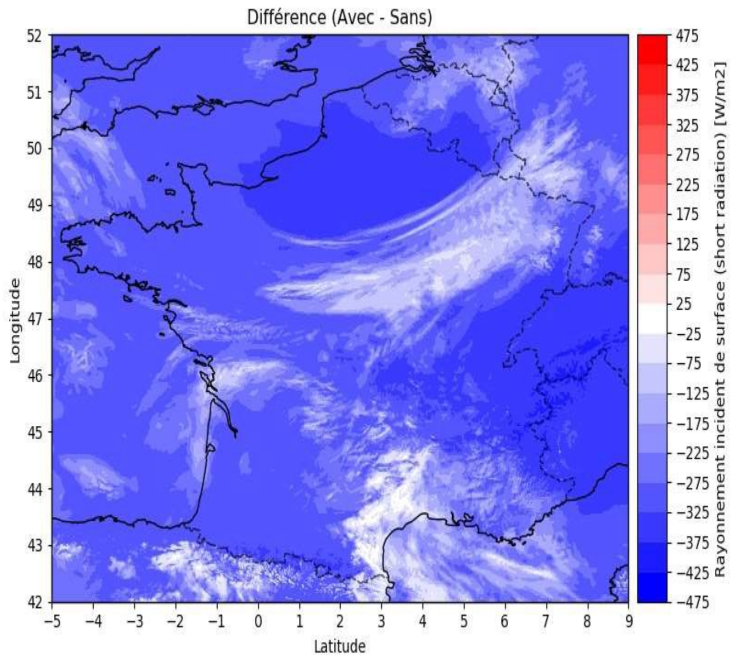
Simulating the solar eclipse of March 20, 2015 with AROME

– the eclipse signal is clearly visible as a reduction of surface radiation downwards (left), moderated by the presence of clouds

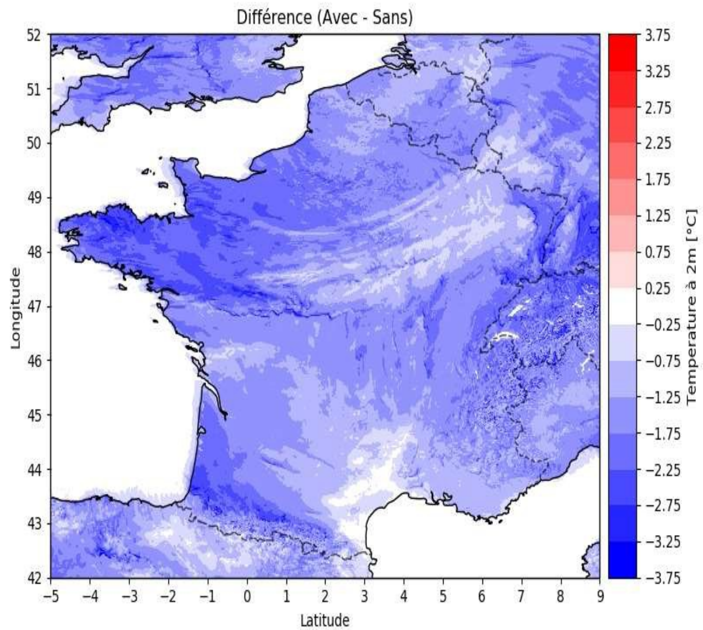
– the eclipse also causes temperature drops of about 3K, consistent with the litterature.

– *(note that for technical reasons this is the March 20, 2015 eclipse simulated with March 20, 2022 meteorological conditions)*

10-h forecast with AROME starting on 25 Oct. 2022, 00 UTC, valid at 10 UTC



Ssrd (differences in W/m^2)



T2m (differences in K)

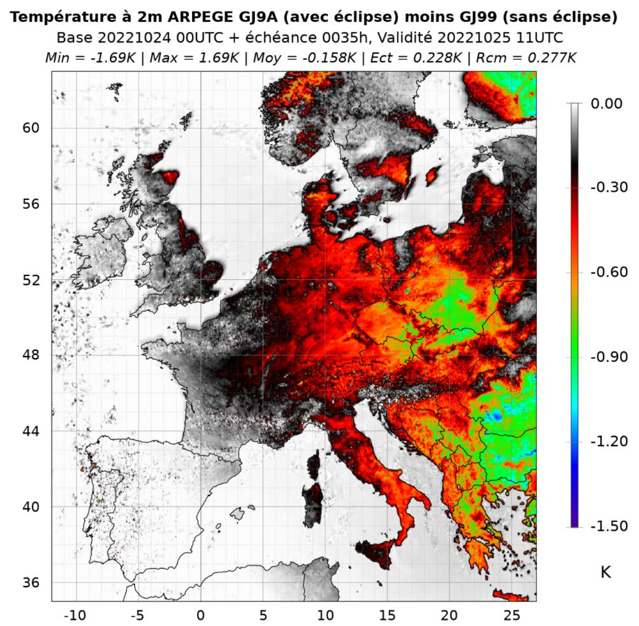
Near real-time simulation of the solar eclipse of Oct. 2022

– Actually, the implementation of solar eclipses in Meteo France Numerical Models was available during the solar eclipse of Oct. 2022

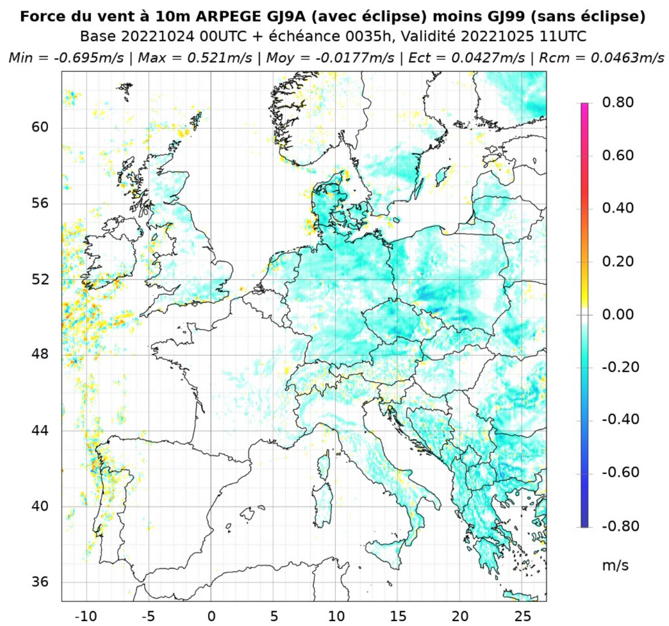
– we have performed near real time simulation of the impact of this eclipse and delivred predictions to RTE and EDF.

– Impact includes a modest reduction of the wind speed (bottom right)

35-h forecast with ARPEGE starting on 24 Oct. 2022, 00 UTC, valid at 11 UTC



T2m (differences in K)



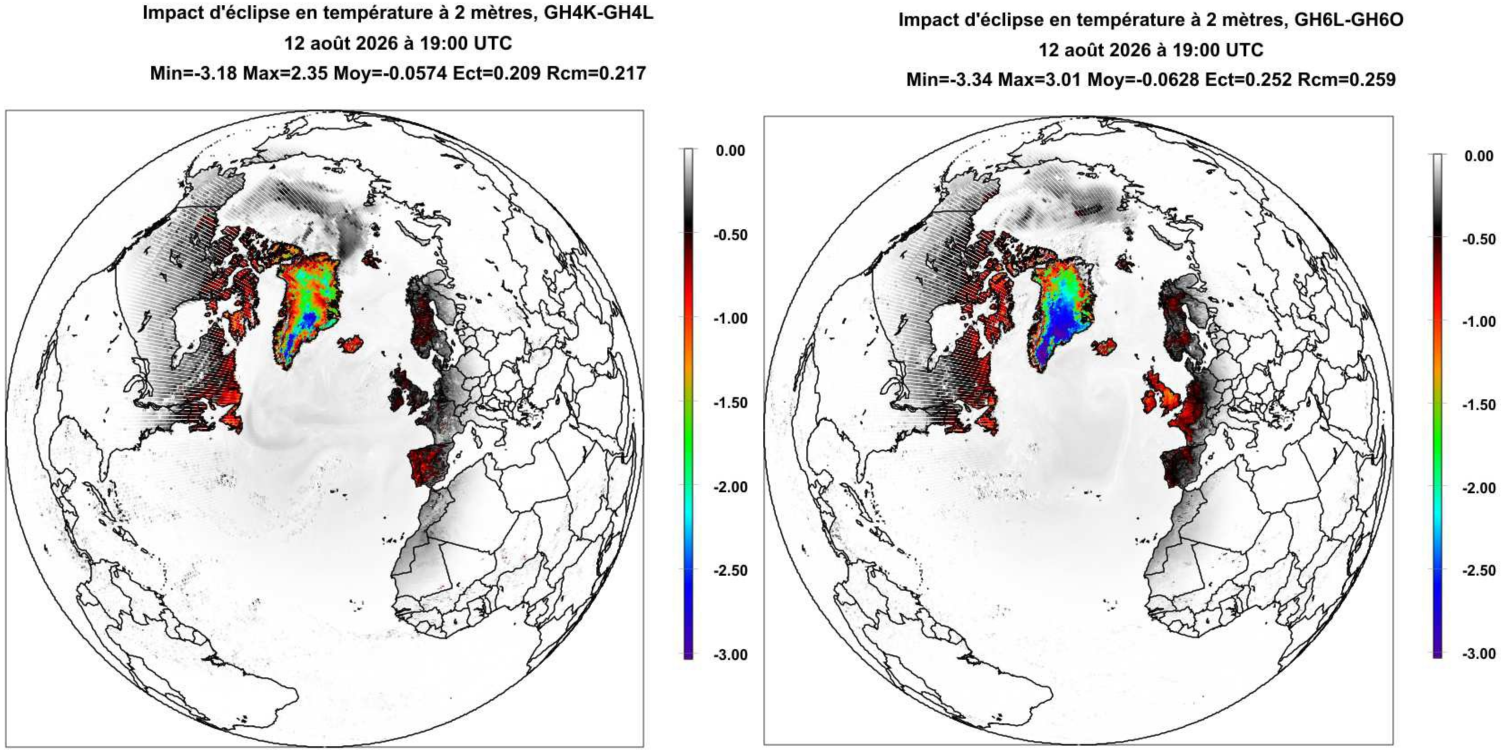
Wind speed (differences in m/s)

Sensitivity of the impact of the eclipse to the meteorological conditions

– Example using the future solar eclipse on 12 August 2026.

– The impact of this eclipse is evaluated with two different initial conditions and performed with clouds removed at every timestep.

– The impact is sensitive to the initial conditions, beyond the occurrence of clouds.



T2m (differences in K)

Conclusions

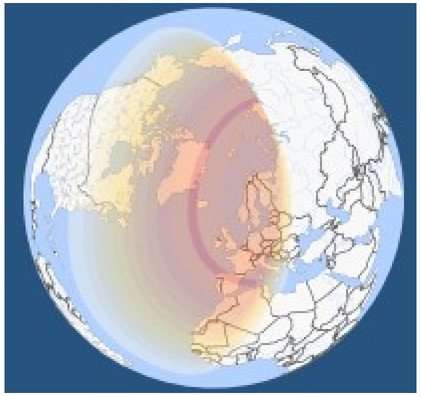
We have incorporated the effect of solar eclipses into AROME and ARPEGE models, allowing for detailed impact studies

– we report impacts of the Oct. 2022 solar eclipse on temperature of the order of 3K, consistent with previous estimates, with strong dependence on cloud cover.

– this solar eclipse also reduced the wind speed, which we attribute to the stabilization of the boundary layer.

– The developements will be made operational in March, 2024, for the benefit of all users of Meteo-France forecasts, and ready for the 2026 solar eclipse !

– future work may consider going up to the impact on forecasted solar production [e.g., Saint Drenan et. Al, *Adv. Sci. Res.* 2018], and further document the sensitivity of the impact of the eclipse to the meteorological conditions.



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